ROBUST DESIGN OF LOWER ARM SUSPENSION USING STOCHASTIC OPTIMIZATION METHOD

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Report submitted in partial fulfillment of the requirements
for the award of the degree of
Bachelor of Mechanical Engineering with Automotive Engineering

Faculty of Mechanical Engineering
UNIVERSITY MALAYSIA PAHANG

NOVEMBER 2009

STUDENT’S DECLARATION

I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted in candidate of any other degree.

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ACKNOWLEDGEMENT

First, I would like to express my grateful to ALLAH s.w.t as for the blessing given that I can finish my project.

In preparing this project, I have engaged with many people on helping me completing this project. First, I wish to express my sincere appreciation to my project supervisor DR. MD. Mustafizur Rahman, for encouragement, guidance, advices, and motivation. Without his continued support and interest, this project would not have been the same as presented here.

Last but not least I acknowledge without endless love and relentless support from my family, I would not have been here. My father, mother, and brothers that always support and encourage me to success.

ABSTRACT

This project presents the development of robust design of lower suspension arm using stochastic optimization. The strength of the design analyze by finite element software. The structural model of the lower suspension arm was mode by using the solidworks. The finite element model and analysis were performed utilizing the finite element analysis code. The linear elastic analysis was performed using NASTRAN codes. TET10 and TET4 mesh has been used in the stress analysis and the highest Von Mises stress of TET10 has been selected for the robust design parameter. The development of Robust design was carried out using the Monte Carlo approach, which all the optimization parameter for the design has been optimized in Robust design software. The improvements from the Stochastic Design Improvement (SDI) are obtained. The design capability to endure more pressure with lower predicted stress is identified through the SDI process. A lower density and modulus of elasticity of material can be reconsidered in order to optimize the design. The area of the design that can be altered for the optimization and modification is identified through the stress analysis result. As a conclusion, the robust design by using stochastic optimization was capable to optimize the lower arm suspension. Thus, all the result from this project can be use as guideline before developing the prototype.

ABSTRAK

Projek ini menerangkankan pembangunan rekabentuk robus untuk “lower arm suspension” mengunakan pengoptimum “stochastic”. Kekuatan rekabentuk telah di kaji mengunakan perisian “finite element”. Struktur model “lower arm suspension” telah di buat dalam “SolidWork”. Model “finite element” untuk rekabentuk dan juga analisis telah dijalankan menggunakan kod “finite element”. Analisis kekenyalan elastik telah dijalankan menggunakan kod NASTRAN. Analisis “TET4” dan “TET10” telah digunakan dalam analisis terikan dan nilai terikan “Von Misses” tertinggi dari “TET10” telah digunakan sebagai parameter di dalam struktur robus. Pembangunan struktur robus telah dijalankan menggunakan kaedah “Monte Carlo” , dimana kesemua telah di optimumkan di dalam perisian struktur robus. Penambahbaikan daripada “Stochastic Design Improvement (SDI)” telah dijalankan. Struktur telah dikenalpasti berupaya menahan tekanan yang lebih tinggi dengan daya terikan yang lebih rendah melalui proses “SDI”. Ketumpatan dan juga “Modulus of elasticity” yang lebih rendah boleh digunakan untuk sruktur “lower arm suspension”. Area putih yang dikenal pasti di dalam analisis terikan telah menunjukkan area tersebut dapat di ubah untuk mengoptimumkan struktur. Kesimpulanya, kesemua hasil yang telah diperoleh di dalam kajian ini dapat digunakan sebagai petunjuk dan panduan bagi pembangunan prototaip “lower arm suspension”.

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LIST OF SYMBOLS

x	is the stochastic variable
y	is the stochastic variable
r	Pearson correlation
u	Mean value
r_s	Spearman correlation
R_i	is the rank of $x_i s$
S_i	is the rank of $y_i s$

LIST OF ABBREVIATIONS

CDM	Continuum Damage Mechanics
DOE	Design Of Experiment
FEA	Finite Element Analysis
FEM	Finite Element Modelling
GRA	Gray Relation Analysis
HIC	Head Injury Criterion
MRR	Material Removal Rate
MCS	Monte Carlo Simulation
OA	Orthogonal Array
RSM	Response Surface Methodology
SPC	Statistical Process Control
SED	Statistical Experimental Design

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

In the automotive industry, the riding comfort and handling qualities of an automobile are greatly affected by the suspension system, in which the suspended portion of the vehicle is attached to the wheels by elastic members in order to cushion the impact of road irregularities. The specific nature of attaching linkages and spring elements varies widely among automobile models. The best rides are made possibly by independent suspension systems, which permit the wheels to move independently of each other. In these systems the unsprung weight of the vehicle is decreased, softer springs are permissible, and front-wheel vibration problems are minimized. Spring elements used for automobile suspension, increasing order of their ability to store elastic energy per unit of weight, are leaf spring, coil spring, torsion bars, rubber-in-shear devices, and air springs.

Following a bump, the undammed suspension (without shocks) of a vehicle will experience a series of oscillations that is cycle according to the natural frequency of the system. Ride is perceived as most comfortable when the natural frequency is in the range of 60 to 90 cycles per minute (CPM). When the frequency approaches 120 CPM (2 Hz), occupants perceive the ride as harsh. Consequently, the suspension of the average family sedan will have a natural frequency of about 60 to 90 CPM. A high-performance sports car have a stiffer suspension with a natural frequency of about 120 to 150 CPM (2 to 2.5 Hz) (Riley.,2003).

For this project, the design of the lower arm suspension will be study. The lower arm design will be create base on robust design and optimize by using the stochastic optimization method. This is ensure that improvement can be made to the basic design of the lower arm suspension with better performance and marketability.

1.2 PROBLEM STATEMENT

Robust design is the process of designing a product or process to be insensitive to the effects of sources of variability. There are external noise, inner noise and unit-to-unit noise. External noise as the name implies comes from outside the product due to effects of elements like temperature and humidity. Inner noise (deterioration noise) is due to aging in products during use or storage. Some examples would include loss of mass of light-bulb filament and weathering of paint on a house. Unit-to-unit noise is the result of never being able to make any two products exactly alike. Typical examples would include dimensions from any metal removing process and batch-to-batch concentration of chemicals (Rakesh, et al.,2002). A stochastic process is a probabilistic model of a system that evolves randomly in time and space. The idea of stochastic optimization consists in combining deterministic optimization methods with uncertainty quantification techniques to measure the sensitivity and the variability of the response. Another objective concerns the reliability-based optimization i.e. the computation of the probability of a risk of failure (Lucor, et al.,2007).With using all these tools, imperfection of the component can be analyzed and can solve in order to find the best solution for the imperfection. The method of robust design can also make sure that a light weight, low cost, and better safety component can be made. By getting all the result in the final process, the component can give a better performance and also give a better market value in the automotive industry.

1.3 SCOPE OF STUDY

The focus is for the robust design of the lower arm suspension using stochastic optimization, the scope for the study are as follows:

i. Structural modeling using Solidwork.

ii. Finite Element modeling and analysis using MSC. PATRAN and MSC. NASTRAN.

iii. Robust design using stochastic optimization method.

1.4 OBJECTIVES OF THE PROJECT

The main objective for this project is to develop a robust design of lower suspension arm using stochastic optimization. The overall objectives are as follow:

i. To design a structural design of lower suspension arm.

ii. To analyze the stress of the lower suspension arm design.

iii. To optimize the lower suspension arm using stochastic method.

1.5 OVERVIEW OF THE REPORT

Chapter 1 gives the brief background of the project. The problem statement, scope of study and the objective are also included in this chapter. Chapter 2 discusses about literature review of the robust designing method, the stress analysis, finite element modeling, and the stochastic optimization method. Chapter 3 presents the development of methodology, finite element modeling and analysis of the lower arm suspension design. Chapter 4 presents the result and discussion of the project. Chapter 5 presents the conclusion and recommendation for the future research of this study.

CHAPTER 2

LITERITURE REVIEW

2.1 INTRODUCTION

The purpose of this chapter is to provide a review of the past research related to the robust design, the stress analysis, and stochastic optimization method.

2.2 ROBUST DESIGN METHOD

In designing part for the automotive industry, robust design method is a very common method that has been use in the industry. The robust design method is very useful in creating or develops a better product for the automotive industry such as lower suspension arm product. Rakesh et al. (2002) were studied about the robust design of a spindle motor. Authors discussed about the way to minimizing variability of products and processes in order to improve their quality and reliability for the spindle motor. The authors also explain about the use of the Response Surface Methodology (RSM) for solving the Robust design problem. The key steps of obtaining a robust design solution through use of RSM are outlined as follows:

1. Identify dominant failure mechanism,

2. Identify the control and noise factors and obtain their feasible ranges,

3. Construct an experimental design,

4. Conduct the design matrix experiments,

5. Use multiple regression analysis to construct the RSM model,

6. Evaluate the mean and the variance either through simulation or through analytical means.

7. Formulate problem and perform a constrained optimisation,

8. Verify the results.

The results of the study show that how robust design techniques could be applied in the design stages of the product development process so as to maximize product reliability.

Zang et al. (2004) was studied about the review of robust optimal design and its application in dynamics. In the studied, the author stated that the objective of robust design is to optimize the mean and minimize the variability that results from uncertainty represented by noise factors. According to the author, most applications of robust design have been concerned with static performance in mechanical engineering and process systems and applications in structural dynamics are rare. The author also stated that the most important task in Taguchi's robust design method is to test the effect of the variability in different experimental factors using statistical tools. The requirement to test multiple factors means that a full factorial experimental design that describes all possible conditions would result in a large number of experiments.

Sreeram (1994) was investigated about the robust design of the automotive suspension system. The author explains about the effective implementation of Statistical Process Control (SPC) and Statistical Experimental Design (SED) methods to improve quality and productivity. The author also explains about the new Quality philosophy was introduced by Taguchi and the combination of some elements of classical design techniques with cost considerations. Author stated that the Taguchi Loss function approach to quality improvement were designed to help find less costly solutions while maintaining high quality and productivity standards. The Response Surface Methodology also mentioned in the author study and has been claimed that these method of robust design is very important for quality improvement which have been used in a number of applications throughout the engineering world and also has been use for the research.

Bharatendra et al. (2004) was studied about the robust design of an interior hard trim to improve occupant safety in a vehicle crash. For this particular study the author aim to achieve the requirements for one such interior component, viz. an interior hard trim that covers the pillar closest to the driver's head on the left-hand side of the vehicle. The author use the finite element analysis tools to build a robust design that gives consistent performance even in the presence of noise factors. From the author definition, a robust design is expected to provide less risk to the occupant and have a lower Head Injury Criteria HIC(*d*) value than a non-robust design. The result of the study stated that to achieve a robust interior hard trim design, the study used separate analyses to identify control factors effecting mean and variability. It helped to achieve low HIC(*d*) values with less variation even under various uncontrollable noise factors.

Kopac and Krajni (2007) was studied about the robust design of flank milling parameters based on grey-Taguchi method. The authors aim for the study dealing with the optimization of the cutting loads, milled surface roughness and the material removal rate (MRR) in the machining of an Al-alloy casting plate for injection moulds. The authors uses the Grey-Taguchi method which combining the orthogonal array (OA) design of experiments (DOE) with grey-relational analysis (GRA), which enables the determination of the optimal combination of flank milling parameters for multiple process responses. From the result of the study using the robust design, the author stated that the flank milling with an end mill with two or three flutes is superior to four-fluted tool. The maximal cutting speed did not yield optimal performance. Reduced feed rates improve the process performance and tool life.

2.3 STRESS ANALYSIS

The stress analysis is very important step in designing any product or part in the automotive industry. By doing the stress analysis on the part we can get the data of the strength and life of the part that have been design. This is very important to determine the best material and the best shape have been use for part design. Seo et al. (2006) carried out a research about the Numerical integration design process to development of suspension parts by semi-solid die casting process. In the research, the authors focus on the practical use and lifetime guarantees for the suspension parts by predicting the stress distribution from the strength analysis and the lifetime from the fatigue analysis. The A356 aluminum alloy was used for the strength and fatigue analyses for the studied. The strength analysis results for the studied were presented with the Von Mises stress distributions and the strain distributions by using five ultimate load conditions and each constraint. From the studied result, the lower arm suspension to which homogeneous stress below the yield strength from the static and dynamic strength analyses was distributed from the analysis that have been done.

Conle and Chu (1998) carried out a study about the fatigue analysis and the local stress–strain approach in complex vehicular structures. The study focus on the observation of stress–strain hysteresis behavior, through the early development of computer versions of the stress–strain shape and memory models, to their evolution into routines that are closely linked to vehicle dynamics models that calculate loads in structures, finite element models that transform the loads into local stresses, and subsequent plasticity correction and damage evaluation routines which yield expected life color contour plots for vehicle body and chassis. The authors explained that in the early days of computerized analysis, this was achieved by scaling an appropriate load histogram with the worst case von Mises' equivalent stress, and then by applying the Neuber correction to each block of stress cycle in the history. In today's relatively complex FEA models similar techniques are still applied. After the complex load history is reduced to a uniaxial (elastic) stress history for each critical element, the Neuber correction is used to compute the local stress and strain. It should be noted here that this method only works well when the critical locations with plasticity are located within large zones of elasticity. When one reaches general yielding of the components, the process breaks down.

Prawoto et al. (2007) carried out a research about the design and failure modes of automotive suspension springs. In the research, a finite element analysis was performed to check the local stress distribution around a given defect using a typical coil spring. The overall stress distribution was checked without any defect in the material, and then at the location where the highest stress was found, each defect was added. Since the size of the defect is significantly smaller than the whole model, a sub modeling technique was used. The authors explained that this technique is used to study a local part of a model with refined meshing based on the FEA result of a global model with coarse meshing. Boundary conditions for the sub model will be automatically interpolated from the global model solution.

Seung (2008) was investigated about the fatigue analysis of an automotive steering link. Finite element method was employed by the authors to determine local stress and strain distributions of the link. The experimental strains at the critical locations in this study were measured by using strain-gages in order to verify the accuracy of the finite element analysis results. From the finite element stress analysis, the authors found that the cracking occurred at the curved region of the tubular steering link rod and propagated circumferentially to the opposite side of the link rod, resulting in the final fracture.

Zhoa et al**.** (2005) carried out a research about the analysis of damage in laminated automotive glazing subjected to simulated head impact. The author focused on occupant’s head impacting on windshield or side window. The author explained that any attempt to design glazing that minimizes injury to and death of occupants during a vehicle accident requires a thorough understanding of the mechanical behavior of automotive glazing subjected to head impact loads. A continuum damage mechanics (CDM) based constitutive model is developed and implemented into an axisymmetric finite element model to study the failure and impact resistance of laminated automotive glazing subjected to simulated head impact. From the study, Damage due to normal principal stress and damage due to shear stress data are collected. Finite element analysis is used to simulate the damage pattern and zone size of a laminated glass panel subjected to normal impact of a featureless headform. The damage pattern and zone size are predicted from the stress analysis.

Kim et al. (2002) were studied a method for simulating vehicles dynamic loads, but they add durability assessment. For their multibody dynamic analysis they use DADS and a flexible body model. The model was for a transit bus. For their dynamic stress analysis , MSC. NASTRAN was used. The fatigue life was then calculated using a local strain approach. From the fatigue life, it was found that the majority of the fatigue damage occurred over a frequency range that depend on terrain traveled (service or accelerated test course). This showed that the actual service environment could be simulated instead of using an accelerated testing environment.

Rahman et al. (2007) were proposed about finite element based durability assessment in a two- stroke free piston linear engine component using variable amplitude loading. Authors discussed the finite element analysis to predict the fatigue life and identify the critical locations of the component. The effect of mean stress on the fatigue life also investigated. The linear static finite element analysis was performed using MSC. NASTRAN. The result was capable of showing the contour plots of the fatigue life histogram and damage histogram at the most critical location.

2.4 STOCHASTIC OPTIMIZATION METHOD

Zang et al. (2004) was studied about the review of robust optimal design and its application in dynamics. The author stated that the objective of stochastic optimization is to minimize the expectation of the sample performance as a function of the design parameters and the randomness in the system. The response surface methodology (RSM) is a set of statistical techniques used to construct an empirical model of the relationship between a response and the levels of some input variables, and to find the optimal responses. In the author's research stated that, Lucas (1994) and Myers et al. (1992) considered the RSM as an alternative to Taguchi's robust design method. Monte Carlo simulation generates instances of random variables according to their specified distribution types and characteristics, and although accurate response statistics may be